Puerto Rico Water Resources & Environmetal Research Institute
Annual Technical Report
FY 2016

Introduction

The Puerto Rico Water Resources and Environmental Research Institute (PRWRERI) is located at the Mayagüez Campus of the University of Puerto Rico (UPRM). The Institute is one of 54 water research centers established throughout the United States and its territories by Act of Congress in 1964 (P.L. 88-379) and presently operating under Section 104 of the Water Research and Development Act of 1984 (P.L. 98-42), as amended. The Puerto Rico Water Resources Research Institute was established in April 22, 1965, as an integral division of the School of Engineering at the College of Agricultural and Mechanic Arts, the official name of UPRM at that time. An agreement between the Director of the Office of the Water Resources Research Institute of the Department of the Interior and the University of Puerto Rico at Mayagüez was signed in May 25, 1965. This agreement allowed the Institute to receive funds as part of the Water Resources Act of 1964. In June 1, 1965, the Chancellor of UPRM appointed Dr. Antonio Santiago-Vázquez as the first director of the Puerto Rico Institute of Water Resources Research. The first annual allotment of funds for fiscal year 1965 was $52,297.29.

Since its inception 52 years ago, the Institute has had eight directors in nine appointment periods as shown in the table below.

Table 1. Directors of the Puerto Rico Water Resources Research Institute (currently Puerto Rico Water Resources and Environmental Research Institute)

Appointment No.; Name; Period of Appointment; Years in Appointment

1 ; Dr. Antonio Santiago-Vázquez; 1965 – 1968; 3

2 ; Eng. Ernesto F. Colón-Cordero; 1968 – 1972; 4

3 ; Eng. Felix H. Prieto-Hernández; 1972 – 1974; 2

4 ; Dr. Roberto Vázquez (acting director); 1974 – 1975; 1

5 ; Dr. Rafael Ríos-Dávila; 1975 – 1980; 5

6 ; Dr. Rafael Muñoz-Candelario; 1980 – 1986; 6

7 ; Eng. Luis A. Del Valle; 1986 – 1989; 3

8 ; Dr. Rafael Muñoz-Candelario; 1989 – 1994; 5

9 ; Dr. Jorge Rivera-Santos; 1995 – Present; 22

The official name of the Institute was changed in 2005 to Puerto Rico Water Resources and Environmental Research Institute.

The general objectives of the Puerto Rico Water Resources and Environmental Research Institute are (1) to conduct research aimed at resolving local and national water resources and environmental problems, (2) to train scientists and engineers through hands-on participation in research, and (3) to facilitate the incorporation of research results in the knowledge base of water resources professionals in Puerto Rico and the U.S. To accomplish these objectives, the Institute identifies Puerto Rico's most important water resources research needs, funds the most relevant and meritorious research projects proposed by faculty from island high level education institutions, encourages and supports the participation of students in funded projects, and disseminates research results to scientists, engineers, and the public.

Since its creation, the Institute has sponsored a substantial number of research projects, supported jointly by federal, state, municipal, private, and University of Puerto Rico's funds. Through its website, the Institute's work is more widely known to the Puerto Rican and world communities and, at the same time, provides means of information transfer with regard to the reports produced through the institute's research activities.

The Institute is advised by an External Advisory Committee (EAC) composed of members from water resources related government agencies, both federal and state levels. This committee virtually convenes annually to established research priorities and to evaluate and recommend proposal for funding under the 104-B program. The EAC has representation from the private sector as well. During EAC meetings, members are supported by the Institute’s Director and Associate Director. Due to recent retirement of some of the members and continues changes in government directorate officials, the Institute’s Director is engaged in recruiting new members for next fiscal year. New agency representatives that may participate in the EAC include the PR Department of Natural and Environmental Resources (PRDNER), Federal Emergency Management Agency (FEMA), US Fish and Wildlife Service (FWS), and US Army Corps of Engineers (CoE).

Research Program Introduction

The Institute functions as a highly recognized advisor to the industry and government sectors on water resources and environmental issues. This role translates into multidisciplinary functions and activities that add relevance and impact to the research program the Institute supports. By virtue of the local relevance of its research and the prestige and leadership of the investigators it has supported, the Institute has become the focal point for water related research in Puerto Rico.

FY-2016 104-B base grant supported two new projects. The project titled “Hybrid multimedia-filter prototype (HMP) for the degradation of trihalomethanes precursors and pathogens control from raw waters,” was aimed to develop and evaluate a hybrid multimedia-filter prototype (HMP) combining glass/TiO2 composite with an intermittent biosand filter (IBSF) to simultaneously treat both NOM and pathogens by photocatalytic and biological processes, respectively. To accomplish the objectives for this endeavor, this one-year project encompassed (1) the design, construction and start-up of 6 lab-scale intermittent biosand filters (IBSFs); (2) optimization and evaluation of different chemical-based techniques to fix TiO2 nanoparticles in a porous, glass substrate; and (3) treatability studies for the IBSFs and the glass-TiO2 composites to access their feasibility in reducing/degrading turbidity, pathogenic microorganisms and humic acids (HA) from synthetic solutions and raw waters.

This project is under a no-cost extension, so, it is still in progress. The PI is still conducting more treatability studies to confirm the preliminary results and reproducibility. Similarly, the glass-TiO2 composite is being characterized by scanning electron microscopy (SEM) to confirm TiO2 polymorph structure and deposition, and composite’s morphology. In addition, some treatability studies are being conducted for humic acid using the photoreactor system. More detailed information on this project can be found later on this report.

The second project is titled “Mapping Field-Scale Soil Moisture Using Ground-Based Passive Microwave Observations Phase II: Application of Remotely Sensed Soil Moisture Data Products for Hydrological Modeling in Puerto Rico.” This is the second phase of this project also by PIs from our home campus. The original proposed project length was three years, corresponding to three phases. This project utilizes the CREST-owned L-band microwave radiometer and SCAN Stations to observe local scale soil moisture (SM) in Puerto Rico. Local SM in complement with meteorological and land surface variables were used for ground validation and downscaling of a satellite soil moisture data product (GCOM-W (AMSR2)). As expected, the validation of the AMSR2 SM product at a 25km resolution with the SCAN-NRCS stations revealed that the AMSR2 spatial coverage of 25km does not provide a good estimate of SM in Puerto Rico. Future research is needed to refine and enhance the downscaled 1 Km SM product. At the present we are working to include more parameters into the downscaling scheme (i.e. changes in elevation, land use, or soil properties). Instrument Calibration and Field Experiment Phase II is being performed during the project No Cost Extension.

FY2016 was an election year resulting in a government administration change in Puerto Rico. This means that most high governmental officials were changed and all MOUs have to be ratified once again. The new administration took office on January 2, 2017 and new appointments have been proposed since then. Nevertheless, the relationship that was initiated during FY2014 with the PR Planning Board (PRPB) was active during this time. This government agency, among other responsibilities, is in charge of receiving, analyzing and resubmitting all hydrologic-hydraulic studies for flood plain delineations and modifications according to FEMA’s regulations. In June 2016, PRPB approved by resolution and adopted the new “Guidelines to Prepare Hydrologic and Hydraulic Studies in Puerto Rico,” guidelines prepared by PRWRERI.

Continuing collaboration with the Puerto Rico Department of Natural and Environmental Resources (PRDNER) has resulted in various externally funded projects. The PRWRERI finished and submitted the

“Guidelines to Prepare Riverbed Material Extraction and Sediment Transport Studies in Rivers of Puerto Rico”. This project consisted in the evaluation of current engineering practices for conducting riverbed material mining and transport studies in the Island. The new guidelines included two reports, namely, “Guidelines to Prepare Riverbed Material Extraction and Sediment Transport Studies in Rivers of Puerto Rico: Technical Manual” and “Guidelines to Prepare Riverbed Material Extraction and Sediment Transport Studies in Rivers of Puerto Rico: Practice Handbook.” These products will influence the DNER’s decision-making process related to the approval of new sand and gravel extraction from rivers and other type of projects that affect natural water bodies.

The Institute continued seeking research funds through the submission of research proposals to federal agencies. During FY2016, the Institute submitted seven proposals to EPA (three proposals), NRCS (one proposal), NOAA (one proposal), PRPB (one Proposal), and to the private sector (one Proposal). One EPA’s and one private sector proposals were approved. EPA’s project titled “Water Conservation, Energy Efficiency and Stormwater Pollution Prevention Assessment on Food Services Establishments, Beauty Salons, and Automobile Maintenance and Repair Shops” has a duration of two years and funding for $568,137, including the matching portion. The proposal submitted to the private consulting firm Tetra Tech and approved for $18,788, included the collection of field data for the MS4 Program of EPA for the Municipality of Hormigueros in Puerto Rico. The proposal submitted to PRPB is still pending of approval, which is very likely.

Hybrid multimedia-filter prototype (HMP) for the degradation of trihalomethanes precursors and pathogens control from raw waters

Basic Information

Title:	Hybrid multimedia-filter prototype (HMP) for the degradation of trihalomethanes precursors and pathogens control from raw waters
Project Number:	2016PR172B
Start Date:	3/1/2016
End Date:	8/31/2017
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Surface Water, Treatment, Water Use
Descriptors:	None
Principal Investigators:	Pedro Javier Tarafa, OMarcelo Suarez

Publications

There are no publications.

Progress Report

PI:	Pedro J. Tarafa, PhD
Project Number:	2016PR172B
Title:	Hybrid multimedia-filter prototype (HMP) for the degradation of trihalomethanes precursors and pathogens control from raw waters.
Submission Date:	May 2nd, 2017

Brief Introduction

This report is intended to provide an update to include preliminary results and accomplishments for the aforementioned research project within the last 6 months of funding (October 2016 – March 2017). The research comprises the: (1) design, construction and start-up of 6 lab-scale intermittent biosand filters (IBSFs); (2) optimization and evaluation of different chemical-based techniques to fix TiO_2 nanoparticles in a porous, glass substrate; and (3) to conduct treatability studies for the IBSFs and the glass-TiO_2 composites to access their feasibility in reducing/degrading turbidity, pathogenic microorganisms and humic acids (HA) from synthetic solutions and raw waters.

Student Training for the Related Period

Below there is a list of all students (graduate and undergraduate) that have been involved in the project, either funded or non-funded.

1. Amir Saffar, MS student from Civil Engineering
   Amir is one out of two graduate students being sponsored by the project. Amir is in charge of the operation and maintenance of the IBSFs, the bacteriological analyses and the treatability studies for the IBSFs and the glass-TiO_2 composites. He has been mentoring a group of two undergraduate students. Amir has been trained with the EPA Method 1604 for pathogens quantification using the Membrane Filtration Technique with mI and mEI medium for E. coli and Enterococcus quantification, respectively. He has been also trained in the use of UV/Vis spectrophotometer and Fluorescence Microscopy technique.

2. Sheila Arias, MS student from Civil Engineering
   Sheila the other graduate student sponsored by the project. She is in charge to design and conduct the tasks stated in the proposal regarding the TiO_2 incorporation into the glass matrix optimization process, TiO_2/glass composite characterization and evaluating the degradation potential of the TiO_2/glass composite for HA. She has been mentoring a group of undergraduate students that are helping in the development and execution of few components for this research. Among other tasks, Sheila was trained in the use and operation of the following key instruments: total organic carbon analyzer (TOC), UV/Vis Spectroscopy, radiometers (light intensity sensors) for UV irradiation, X-ray diffraction analysis (XRD), infrared spectroscopy (FTIR), HACH spectrophotometer, nuclear magnetic resonance (NMR) spectroscopy and Raman spectroscopy.

3. Wadson Phanord, Undergraduate student from Civil Engineering
   Wadson was an undergraduate student (up to December 2016) that was financially sponsored by the project. Wadson helped in the design and construction of the IBSFs and provides support for the operation and maintenance of the IBSFs. He provided support with the photodegradation studies. He was trained in the EPA protocols and membrane filtration technique for E. coli and Enterococcus quantification in water.

4. Jaime Pérez Rivera, Undergraduate student from Civil Engineering
   Jaime is an undergraduate student that has been providing assistance to both Sheila an Amir in the evaluation of immobilization techniques to effectively fix TiO_2 particles onto the SGS. His main duties consist in designing a method for conducting porosity analyses for the bulk SGS and GTC composites. During this experience, Jaime has been trained in the sintering protocol of crushed glass dealing with muffle furnaces, TiO_2 suspension and coating preparation, high precision analytical balances, among others.

5. Stephanie Nieves, Undergraduate student from Civil Engineering
   Stephanie joined our research team this semester (January 2017) through the course INCI 4998 (Undergraduate Research). She has been trained in the EPA approved protocols for E. coli and Enterococcus quantification to give support in the biofilters experiments and has been trained also in the detection of total organic carbon (TOC) using the Simplified Total Organic Carbon Vial Testing Method from HACH. In this sense, Stephanie, has been involved in the construction of a reliable calibration curve for the detection of TOC from water samples from a correlation between the HACH method and the absorbance response of an UV/vis spectrometer.

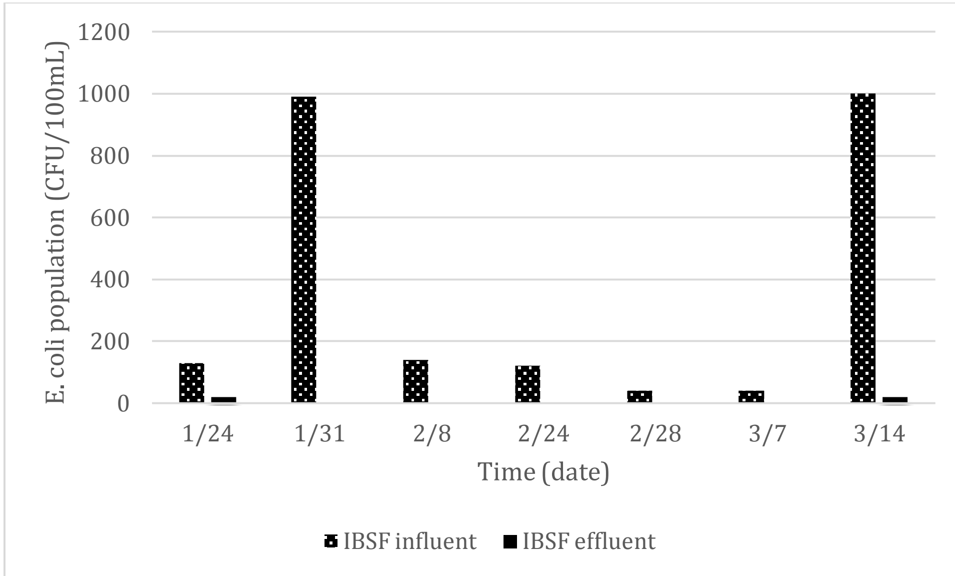
Results Dissemination

N/A

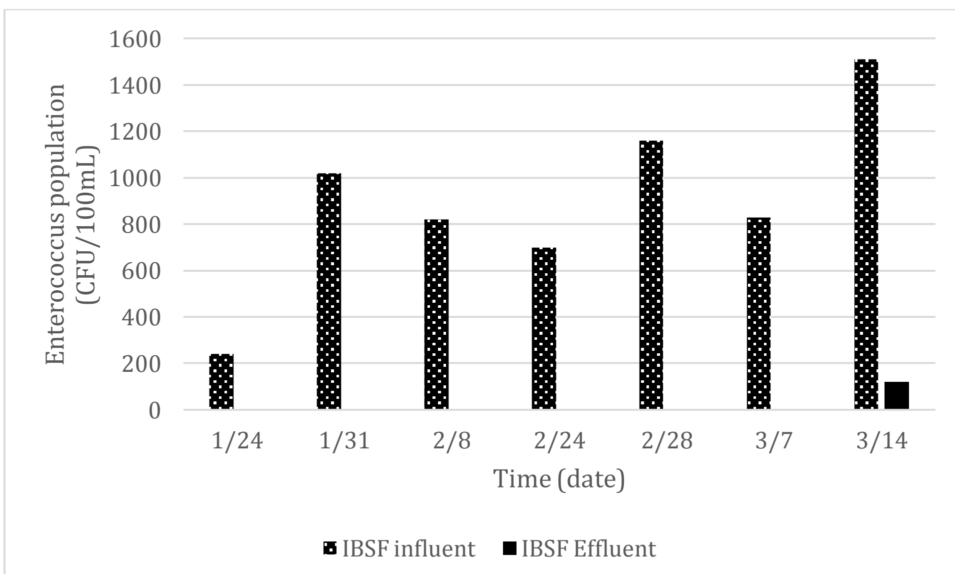
Work Performed

1. <u>Maintenance and operation of the IBSF</u>

   The filters (IBSFs) have been kept in operation. The filters are designed to operate in batch mode in order to keep the biolayer healthy and alive, so a new batch of raw water is filtered every 24 hours. Bacteriological analyses have been performed by monitoring the filters' influent and effluent once per week. Figure 1 shows the bacteria population profile within the last three months for both E. coli (a) and Enterococcus (b).



(a)



(b)

Figure 1. Bacteriological analysis profile for IBSF: (a) E. coli quantification; (b) Enterococcus quantification. All reported data pertain to Year 2017.

From both plots (a and b) in Figure 1, it can be inferred that a biolayer is effectively established as there is a significant drop in the E.coli and Enterococcus population when the influent (raw water) and effluent flows to and from the IBSF are compared. The E. coli removal was 100% for almost all the data except for January 24 and March 14, where it was 85 and 98%, respectively. Similarly, the reduction of Enterococci population was consistent for almost all the monitored days, yielding a 100% removal except for the last data point (March 14) where a 92% efficiency was attained. It needs to be pointed out that for that specific day (March 14), the Enterococci population in the influent, raw sample was the highest one detected for all the monitoring period. By evaluating these data, it can be concluded that the filter has reached its optimal and maximum capability to reduce/destroy both E. coli and Enterococcus.

2. Vial testing and absorbance correlation for TOC quantification

In order to properly identify the amount of TOC in the water samples by the spectrometry method, it was necessary to do a comparison line between the instrument's absorbance (spectrometer) and the HACH vial testing method. Using the response of a low range TOC vial test and the UV/vis spectrometry readings of multiple samples we acquired the data shown in Table 1 and Figure 2.

Table 1. TOC levels and their respective absorbance response for multiple water samples taken from Quebrada de Oro creek

Sample	Absorbance (254 nm)	TOC (mg/L)
1	0.0165	2.67
2	0.055	9.35
3	0.0349	6.7667
4	0.073	11.3
5	0.044	8.5
6	0.037	2.4
7	0.032	4.78
8	0.041	7.895
9	0.0836	11.24
10	0.03	5.3
11	0.0134	4.75
12	0.055	8.2
13	0.07	12.7
14	0.055	8.2
15	0.065	10.2
16	0.05	7.6

The above data pertain to samples collected from mid-November 2016 and late March 2017 to represent a wide range of TOC levels in water. Figure 2 shows a plot of the collected data in Table 2 in order to construct a calibration curve to correlate the absorbance against the TOC levels. This will serve as an alternative to the costly vial tests method as a way to determine the TOC content of any water sample by a simple spectrometry analysis.

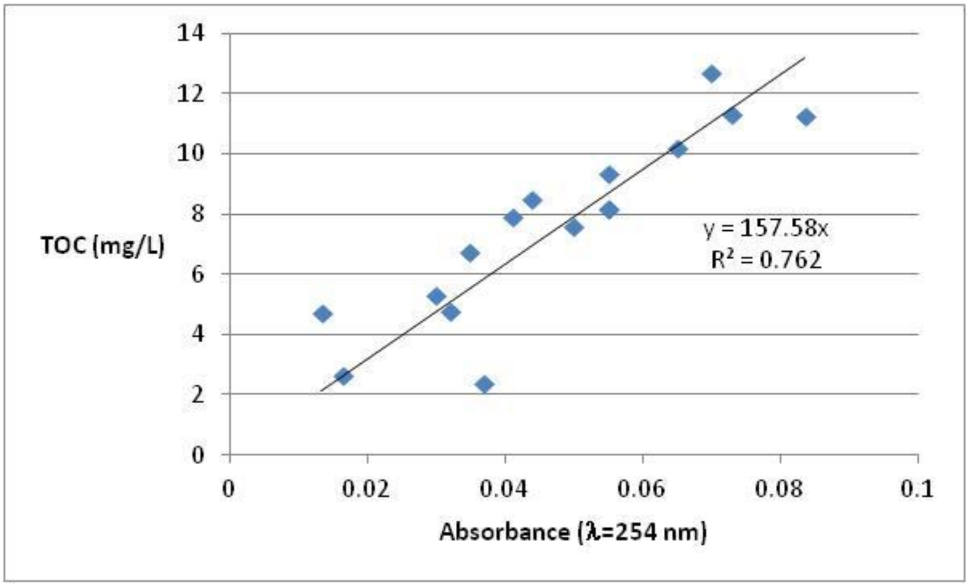


Figure 2. Correlation between TOC levels and absorbance as detected by the UV/vis spectrometer for multiple water samples

3. Preliminary treatability studies coupling together the IBSF and the glass-TiO_2 composite in series for the reduction of E. coli, Enterococci and natural organic matter

   This step is intended to observe the effect in both pathogen and organic matter levels in water samples after being treated by the HMP. Figure 3 presents a schematic of the experimental design with their sampling points.

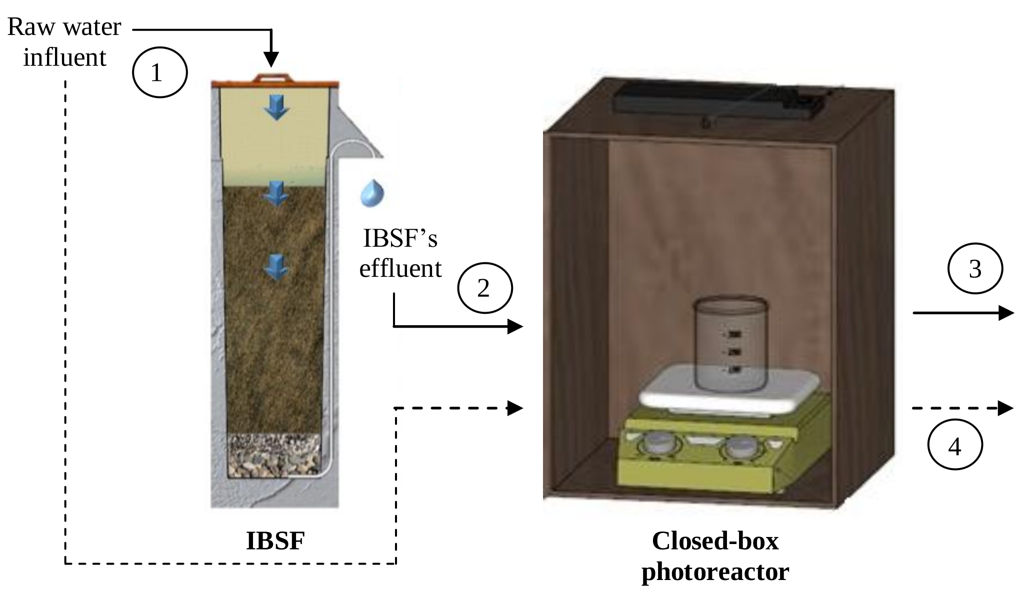


Figure 3. HMP array for treatability studies and their sampling points (denoted by circled numbers)

The treatability studies consisted first in taking any given raw water sample from the Quebrada de Oro creek and allow it to be filtered through the IBSF. Once filtered, the IBSF effluent is placed in contact with the glass-TiO_2 composite within a beaker inside the closed-box photoreactor. The UV light lamp (on top of the closed-box) is turned on to allow the photo-reaction while the water sample is kept stirred. The photodegradation test is carried out at different time periods.

Another set of experiments are carried out by-passing the IBSF (denoted in Figure 3 by a dashed line). In this scenario, the raw water was sent directly to the photoreactor (no filtration) and treated accordingly. Samples at different points are taken and monitored for E. coli and Enterococcus population as well as for TOC levels. The monitoring points are described as follows: Point 1 denotes raw (untreated) water; Point 2 denotes IBSF effluent (which becomes photoreactor influent); Point 3 stands for a water sample (previously filtered) treated in the photoreactor for a certain amount of time; and Point 4 refers to a water sample been treated in the photoreactor without previous filtration (no IBSF treated). In order to explore any individual effect on the reduction of the pathogens and organic matter due to aging, adsorption and/or UV light itself; three different controls are run in parallel. Control 1 consists in a raw water sample left aside the IBSF for 24 hour; Control 2 consists in a water sample taken from the IBSF effluent and placed in the photoreactor box with no UV light; Control 3 refers for a raw, unfiltered water sample placed in the closed-box photoreactor in contact with the glass-TiO_2 composite but with no UV light. Table 2 presents the data acquired from a preliminary work. The data collected from the photoreactor pertain for a two-hour period run.

Table 2. Enterococus, E. coli and TOC levels for all samples taken during the treatability study described in Figure 3

Monitoring point	Enterococcus (CFU/100 mL)	E. coli (CFU/100 mL)	TOC (mg/L)
1	880	210	8.48
2	20	10	4.29
3	0	0	4.17
4	540	150	6.70
Control 1	920	250	9.64
Control 2	0	0	4.56
Control 3	650	180	8.04

From Table 2, it can be observed that significant reductions on Enterococcus and E. coli are attained within the IBSF for an equivalent filter efficiency of 97.73% and 95.23, respectively, for each pathogenic microorganism. In terms of TOC, it is also seen a considerable reduction of 49.41% by the IBSF. When the data in Monitoring Point 2 is compared to Control 1 one can conclude that the reductions in such parameters can be attributed to the IBSF since the levels in Control 1, which is a raw water sample left aside for 24 hours, did not exhibit any drop. For those samples treated in the photoreactor with the glass-TiO_2 composite and UV light (shown in Monitoring Point 3), no E. coli and

Enterococcus population were detected, which suggests that the treatment in this point will be able to destroy any residual pathogen. However, in order to confirm this statement, in our next trial we will be running another control consisting of a duplicate water sample taken from the IBSF effluent and left outside the photoreactor. The fact that Control 2 (sample taken from the IBSF effluent and placed in the photoreactor with no UV light) shows no residual levels of Enterococcus and E. coli may implies that the reduction of these pathogens could be attributed to adsorption onto the glass-TiO_2 composite. In terms of TOC, at Monitoring Point 3, practically there was no reduction (although there is a reduction of 0.12 mg/L after been phototreated). In the last trial where the IBSF was completely avoided/bypassed (i.e. treatment consisted in the photoreactor alone), the treatment efficiency for the raw water sample in terms of Enterococcus, E. coli and TOC was 38.63, 28.57 and 21%, respectively. When Control 3 (same unfiltered, raw water sample placed in the photoreactor with no UV light) is observed, some reduction of Enterococcus and E. coli is detected, which may confirm an adsorption phenomenon between the composite and the pathogens. No realistic reduction is seen for the TOC level, which suggests that in the absence of UV light no organic matter degradation is feasible.

Additional comments:

The project is under a no-cost extension, so, it is still in progress. We are still conducting more treatability studies to confirm the preliminary results and reproducibility. Similarly, the glass-TiO_2 composite is being characterized by scanning electron microscopy (SEM) to confirm TiO_2 polymorph structure and deposition, and composite's morphology. In addition, some treatability studies are being conducted for humic acid using the photoreactor system. Most of these data and results will be presented in Sheila's thesis, which is expected to be completed by this month. Also, an abstract was submitted and accepted for the 2017 Latin American and Caribbean Consortium of Engineering Institutions (LACCEI) to present and publish our work in a conference proceeding. This will be held in Boca Raton, FL on July 18-20, 2017.

Mapping Field-Scale Soil Moisture Using Ground-Based Passive Microwave Observations Phase II: Application of Remotely Sensed Soil Moisture Data Products for Hydrological Modeling in Puerto Rico

Basic Information

Title:	Mapping Field-Scale Soil Moisture Using Ground-Based Passive Microwave Observations Phase II: Application of Remotely Sensed Soil Moisture Data Products for Hydrological Modeling in Puerto Rico
Project Number:	2016PR174B
Start Date:	3/1/2016
End Date:	8/31/2017
Funding Source:	104B
Congressional District:	PR
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Models, Agriculture
Descriptors:	None
Principal Investigators:	Jonathan MunozBarreto

Publications

There are no publications.

Progress Report (As of April 2017)

PI:	Jonathan Muñoz-Barreto, PhD
Project Number:	2016PR174B
Title:	Mapping Field-Scale Soil Moisture Using Ground-Based Passive Microwave Observations Phase II: Application of Remotely Sensed Soil Moisture Data Products for Hydrological Modeling in Puerto Rico
Submission Date:	April 31, 2017

Brief Introduction

This report is intended to provide the biannual (2nd) progress of the abovementioned research project. It comprises: (1) Task 2: Cross-comparison of In-Situ vs. Satellite soil moisture data and (2) Task 3: Downscaling and Hydrological modeling (HL-RDHM).

Task 4: Instrument Calibration and Field Experiment Phase II will be completed during the project No Cost Extension.

Background

This project utilizes the CREST-owned L-band microwave radiometer and SCAN Stations to observe local scale soil moisture (SM) in Puerto Rico. Local SM in complement with meteorological and land surface variables were used for ground validation and downscaling of a satellite soil moisture data product (GCOM-W (AMSR2)).

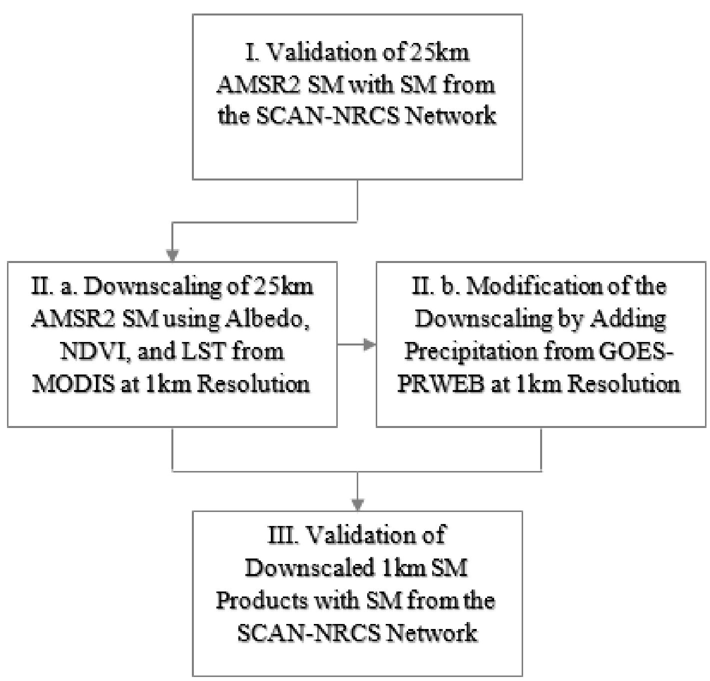


Figure 1: Validation and Calibration Flow Chart

Student Training

1. *Jonathan Nuñez*, MS student from Civil Engineering
   Jonathan is the lead student for this endeavor and the only graduate student sponsored by the project (2016PR169B). He was in charge of conducting the tasks stated in the proposal regarding the interpretation and downscaling of satellite soil moisture (SM) data. He will defend his thesis (May 11th, 2017) based on this study.

   Mr. Nuñez was accepted (Full Scholarship) to the doctoral program at the Department of Civil Engineering at the City College of New York. Other accomplishment of Mr. Nuñez include, spending summer 2016 at the Engineering, Research and Development Center of the U.S. Army Corp of Engineering working with soil moisture sensing science.

2. *Steven Aviles*, Undergraduate Student from Land Surveying and Topography
   Steven is an undergraduate student that works with Dr. Jonathan Muñoz research group. He was sponsored by the project (2016PR169B) and his work was to acquire and process the SM data.

Results Dissemination

Conferences:

1. Title: Evaluation of the JPSS GCOM-W Soil Moisture Product in the Caribbean region: A Case Study for Puerto Rico
   Authors: Jonathan Muñoz-Barreto, Tarendra Lakhankar & Jonathan Nuñez
   Event: NOAA Cooperative Institute for Climate and Satellites Science Conference
   Place: University of Maryland, College Park, MD
   Date: 29 Nov – 1 Dec, 2016

Publications:

1. Muñoz, Nuñez & Lakhanka , *Early Results of the Puerto Rico Satellite Soil Moisture Test-Bed*, in preparation to be submitted (*Summer 2017*) to Hydrology and Earth System Science (HESS) journal - ISSN 1027-5606.

Work Performed

1. **Task 2:** Cross-comparison of In-Situ vs. Satellite soil moisture data.

For the cross-comparison of the entire collection of 25km resolution AMSR2 SM product, all data available from all the SCAN-NRCS stations over Puerto Rico was processed. To analyze the behavior of the AMSR2 SM products in terms of each individual SCAN-NRCS station, the location of each ground-based station was matched with the closest AMSR2 25Km pixel centroid.

Furthermore, to reduce the bias in the analysis, SM values were filtered for all days where the SM bias does not exceed a range of ±0.15 *(vol/vol)* of error.

Validation Summary:

Table 1 & 2 provide the basic statistics of the validation. These tables include the maximum, minimum, average, mode, variance, and standard deviation for all SM data from 2012-2016 on each SCAN-NRCS station and the compared AMSR2 SM values.

For most SCAN-NRCS stations it can be observed that the AMSR2 maximum SM is very similar, while in the minimum, AMSR2 tends to underestimate. The average and mode are mostly below the medium SM value, reinforcing the premise that AMSR2 tends to underestimate SM in Puerto Rico.

Comparing column 1 and 2 with column 4 from table 1, it can be concluded that as AMSR2 coverage increase (days with data) above any SCAN-NRCS station, the correlation increases. When the available data pixel is farther away (> 12.5 kilometers) from the station, the correlation decreases. Also, the magnitude of the correlation depends on the quantity of values that are being analyzed inside the error range.

Table1. Average distance, frequency of biased, and correlation coefficient for the validation in each SCAN-NRCS station.

#	Station	Adjuntas	Cabo Rojo	Corozal	Guánica	Isabela	Juana Díaz	Maricao	Mayagüez
1	Average Minimum Distance: Station to Centroid	12.4km	32.0km	11.4km	14.2km	35.9km	13.1km	33.8km	32.1km
2	Percent inside 12.5km buffer	91%	42%	95%	42%	7%	31%	2%	35%
3	Percent inside ±0.15 error range	25%	43%	25%	44%	28%	64%	43%	6%
4	R^2	0.8417	0.3027	0.7269	0.4075	0.7532	0.4999	0.3027	0.4556

Table 2. Overall basic statistics for each SCAN-NRCS station validation

Adjuntas	NRCS SM	AMSR2 SM
Maximum	0.6060	0.599
Minimum	0.1190	0.009
Average	0.2549	0.205
Mode	0.1960	0.078
Variance	0.0129	0.0225
Std. Deviation	0.1137	0.1500

Cabo Rojo	NRCS	AMSR2
Maximum	0.318	0.386
Minimum	0.107	0.009
Average	0.155	0.100
Mode	0.128	0.069
Variance	0.0012	0.0048
Std. Deviation	0.0348	0.0696

Corozal	NRCS	AMSR2
Maximum	0.523	0.567
Minimum	0.118	0.021
Average	0.230	0.179
Mode	0.179	0.136
Variance	0.0067	0.0117
Std. Deviation	0.0817	0.1080

Guánica	NRCS	AMSR2
Maximum	0.342	0.348
Minimum	0.004	0.009
Average	0.067	0.085
Mode	0.021	0.078
Variance	0.0027	0.0028
Std. Deviation	0.0521	0.0524

Isabela	NRCS	AMSR2
Maximum	0.478	0.571
Minimum	0.118	0.026
Average	0.250	0.190
Mode	0.213	0.216
Variance	0.0075	0.0133
Std. Deviation	0.0865	0.1152

Juana Díaz	NRCS	AMSR2
Maximum	0.434	0.552
Minimum	0.112	0.009
Average	0.191	0.149
Mode	0.145	0.094
Variance	0.0030	0.0071
Std. Deviation	0.0546	0.0842

Maricao	NRCS	AMSR2
Maximum	0.318	0.386
Minimum	0.107	0.009
Average	0.155	0.100
Mode	0.128	0.069
Variance	0.0012	0.0048
Std. Deviation	0.0348	0.0696

Mayagüez	NRCS	AMSR2
Maximum	0.584	0.599
Minimum	0.454	0.318
Average	0.553	0.543
Mode	0.566	0.587
Variance	0.0008	0.0041
Std. Deviation	0.0276	0.0643

2. **Task 3:** Downscaling and Hydrological modeling

Downscaling of AMSR2 Soil Moisture Products

The 25km resolution SM product from AMSR2 was downscaled (Figure 2) using a methodology originally presented in a study by Ray et al. (2010). This methodology uses 1km MODIS data for Albedo, NDVI, and LST to produce a 1km resolution SM estimate. It is important to clarify that the original proposal included a method developed by Seo et al. 2014, however due difficulties in the implementation it was exchanged.

The following equation was used in the downscaling process:

$$\theta_s = \sum_{i=0}^{i=n}\sum_{j=0}^{j=n}\sum_{k=0}^{k=n} a_{ijk} V^i T^j A^k$$

For each individual pixel n the soil moisture is estimated as:

$$\theta_s = a_{000} + a_{001}A + a_{010}T + a_{100}V + a_{011}TA + a_{101}VA + a_{110}VT$$

Each MODIS parameter is upscaled to match the AMSR2 resolution using the following equations:

$$V_{25km} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} V_{ij}}{mn} \qquad T_{25km} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} T_{ij}}{mn} \qquad A_{25km} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} A_{ij}}{mn}$$

The upscaling is done by calculating an average value of all the 1km MODIS pixels that are inside each 25km soil moisture product of GCOM-W. Once the upscaling is done, the regression coefficients $a_{\#\#\#}$ are calculated and proceeded to the downscaling. The downscaling was done by equation:

$$\theta_s = -1.2067 + 53.3466\,A + 0.0049\,T - 0.9109\,V - 0.1820\,TA + 1.676\,VA + 0.0027\,VT$$

The regression model achieved a moderate correlation of 0.6102 and an overall RMSE of 0.0050, indicating that the model did a good fit with the AMSR2 estimates. The resulted product shows promise; the new 1 Km SM data product offers smaller bias and SM values more representative to local surface heterogeneity and meteorology.

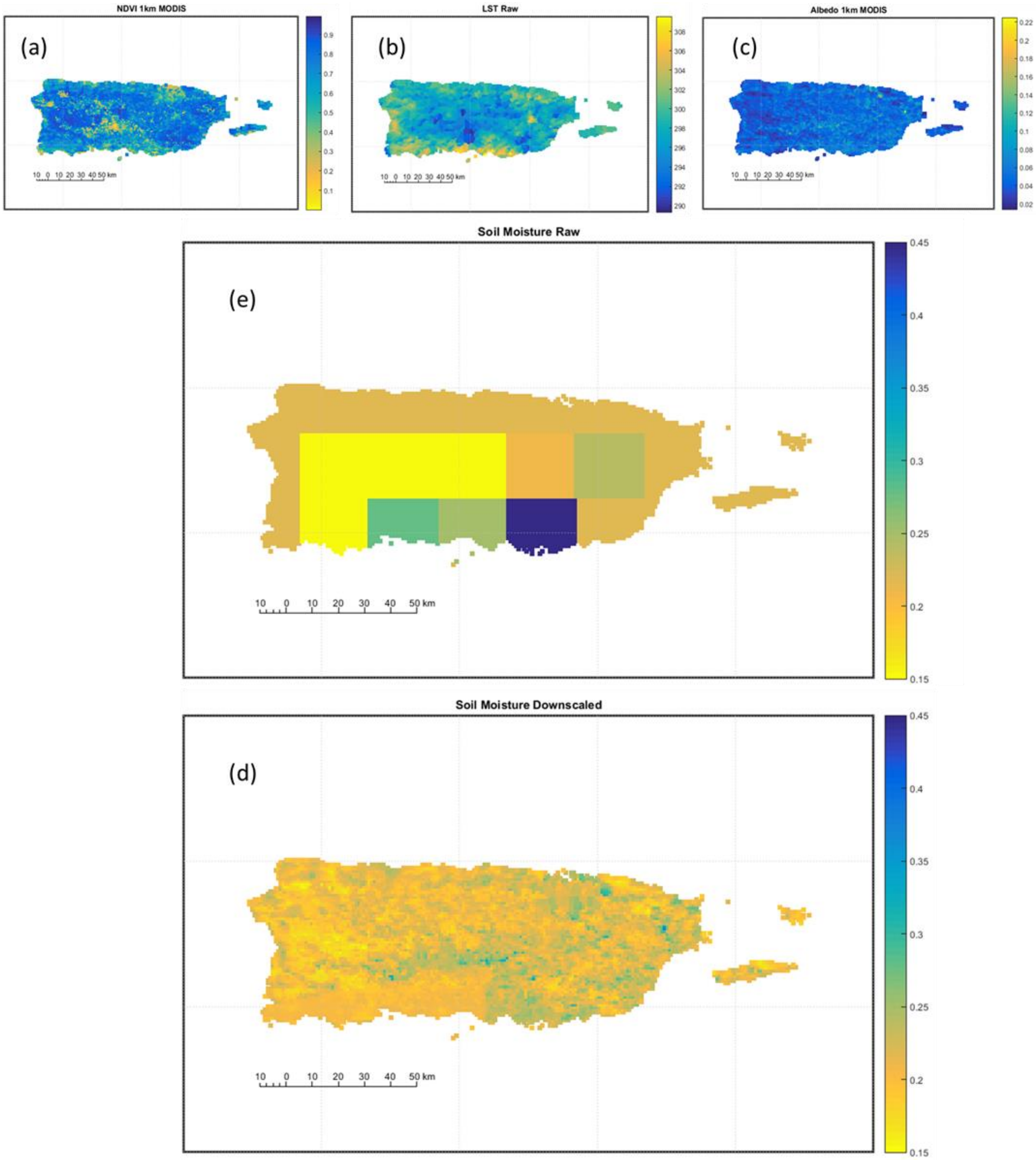


Figure 2: MODIS Downscaling parameters at 1Km resolution: (a) NDVI, (b) LST (c) Albedo, (d) GCOM-W soil moisture at 25 Km and (e) Downscaled GCOM-W soil moisture data at 1KM

Validation of Downscaled SM Product

Table 3 and 4 provide the basic statistics for the downscaling. These tables include the maximum, minimum, average, mode, variance, and standard deviation for all SM data from 2012-2016 on each SCAN-NRCS station and the compared downscaled SM values. For most SCAN-NRCS stations it can be observed that the AMSR2 maximum SM is very similar, while in the minimum, the downscaled values still tend to underestimate, but at a slightly less magnitude than the AMSR2 25km values. The average and mode are mostly below the medium SM value, reinforcing the fact that the downscaling model is also underestimating SM in Puerto Rico.

To expand the spatial coverage of the downscaled product to the entire region of Puerto Rico, a daily average SM from the 25km pixels was calculated and assumed in all regions not covered by the AMSR2 25Km product. Since the downscaled SM covers the entire island at a 1km resolution, spatial coverage in no longer an error source. Though, this assumption led to an increase in instances where the bias is ±0.15, and to a slight decrease in the correlations. The increase in instances inside the bias range is an enhancement. On the other hand, the decrease in the correlations is a negative effect from the assumption of an average daily SM value.

Table 3. Frequency of biased, and correlation coefficient for the validation of the downscaled SM in each SCAN-NRCS station.

Station	**Adjuntas**	**Cabo Rojo**	**Corozal**	**Guánica**	**Isabela**	**Juana Díaz**	**Maricao**	**Mayagüez**
Percent inside ±0.15 error range	33%	50%	30%	45%	41%	70%	84%	1%
R^2	0.6206	*0.2399*	0.7231	0.4648	0.6369	0.3752	0.5327	0.6705

Table 4. Overall basic statistics for the validation of the downscaled SM in each SCAN-NRCS station.

Adjuntas	NRCS SM	AMSR2 SM
Maximum	0.574	0.537
Minimum	0.119	0.042
Average	0.238	0.193
Mode	0.217	0.042
Variance	0.0061	0.0086
Std. Deviation	0.0782	0.0929

Cabo Rojo	NRCS	AMSR2
Maximum	0.333	0.326
Minimum	0.107	0.023
Average	0.165	0.137
Mode	0.128	0.023
Variance	0.0020	0.0041
Std. Deviation	0.0450	0.0644

Corozal	NRCS	AMSR2
Maximum	0.536	0.540
Minimum	0.118	0.033
Average	0.243	0.201
Mode	0.179	0.033
Variance	0.0082	0.0102
Std. Deviation	0.0905	0.1008

Guánica	NRCS	AMSR2
Maximum	0.376	0.484
Minimum	0.004	0.023
Average	0.072	0.126
Mode	0.022	0.023
Variance	0.0034	0.0031
Std. Deviation	0.0583	0.0554

Isabela	NRCS	AMSR2
Maximum	0.478	0.540
Minimum	0.118	0.028
Average	0.257	0.204
Mode	0.213	0.028
Variance	0.0064	0.0084
Std. Deviation	0.0799	0.0915

Juana Díaz	NRCS	AMSR2
Maximum	0.445	0.430
Minimum	0.112	0.023
Average	0.189	0.156
Mode	0.163	0.023
Variance	0.0028	0.0056
Std. Deviation	0.0531	0.0745

Maricao	NRCS	AMSR2
Maximum	0.396	0.515
Minimum	0.084	0.022
Average	0.178	0.137
Mode	0.194	0.022
Variance	0.0032	0.0062
Std. Deviation	0.0568	0.0786

Mayagüez	NRCS	AMSR2
Maximum	0.578	0.522
Minimum	0.454	0.334
Average	0.536	0.435
Mode	0.568	0.334
Variance	0.0019	0.0026
Std. Deviation	0.0435	0.0511

Conclusion

As expected, the validation of the AMSR2 SM product at a 25km resolution with the SCAN-NRCS stations revealed that the AMSR2 spatial coverage of 25km does not provide a good estimate of SM in Puerto Rico. The overall results of the validation show that about 35% of the AMSR2 SM estimates behaves similar (±0.15) to the SCAN-NRCS SM measurements with an overall correlation of 0.5363. The low correlation between the coarse resolution estimate and the ground-based measurements is due to changes in vegetation density, land use, topography, precipitation, and soil properties in Puerto Rico.

The downscaling method provided a good fit with the AMSR2 data. The resulting SM from the linear equation that relates Albedo, LST, and NDVI from MODIS with the SM from AMSR2 showed a tendency to increase SM where a precipitation event occurred. This enhancement increased the percent of AMSR2 estimates that behaves like the ground-based measurements to 44%, but slightly decreased the correlation to 0.5330. To expand the coverage of the AMSR2, a daily average SM value was assumed for the area that was left out of the 25km grids. This assumption led to the decrease in correlation and can be modified in future research. The addition of a precipitation in the downscaling methodology shows promise reducing the underestimation of the new developed 1 Km AMSR2 SM product.

Future research is needed to refine and enhance the downscaled 1 Km SM product. At the present we are working to include more parameters into the downscaling scheme (i.e. changes in elevation, land use, or soil properties).

Future Work

Task 4: Instrument Calibration and Field Experiment Phase II will be performed during the project No Cost Extension.

Accomplishments

Operational 1Km (AMSR2 based) SM product for Puerto Rico, daily maps will be generated and made available online. The Downscaled SM product (2012-present) will be available for download in .png, .mat and .csv formats. Preliminary the data will be host at https://wordpress.uprm.edu/elige/mdocuments-library/

Information Transfer Program Introduction

Meetings, seminars, technical reports, and a web site are used by the Institute to keep the water resources community and general public informed about advances in research. Approximately once every three or four years, the Institute organizes a major conference on water-related research in Puerto Rico and the Caribbean Islands, in collaboration with US Virgin Islands Water Resources Research Institute, Caribbean office of the USGS, and professional organizations in the region. All these activities facilitate the translation of research sponsored by the Institute into practical applications of direct benefit to industry, government, and the public. In 2015, the last conference held, the Puerto Rico Water Resources and Environmental Research Institute joined the Hawaii Water Resources Research Center, the Virgin Islands Water Resources Research Center, and the Environmental Research Institute of the Western Pacific in Guam to organize the conference titled “2nd Water Resource Sustainability Issues on Tropical Islands.” Next conference is being coordinate with the Islands Institutes for April 2018. This information transfer project was partially funded from 104B program.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	0	0	0	4
Masters	6	0	0	0	6
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	12	0	0	0	12

Notable Awards and Achievements

Approval and adoption of the "Guidelines to Prepare Hydrologic and Hydraulic Studies in Puerto Rico" by the Puerto Rico Planning Board (PRPB). June 2016.

Approval and adoption of the "Guidelines to Prepare Riverbed Material Extraction and Sediment Transport Studies in Rivers of Puerto Rico" by the Puerto Rico Department of Natural and Environmental Resources (PRDNER). December 2016.